

In the Drawings:

- 1) A corrected Replacement Sheet for Fig. 1 is enclosed. The following corrections were made:
  - a) box 1 has been labeled:  
internal combustion engine
  - b) the arrow head at the top of box 1 into box 1 has been removed
  - c) the word "portions" in the label of box 6 has been changed to --orders--
  - d) "closed loop" has been added to the label of box 8.
- 2) The foregoing corrections do no involve any new matter. Entry of the replacement sheet of Fig. 1 into the official file is respectfully requested.

**[RESPONSE CONTINUES ON NEXT PAGE]**

REMARKS:

- 1) Referring to section 1 on page 2 of the Office Action, the Examiner's presumption is correct the subject matter of the various claims was commonly owned at the time the inventions were made.
- 2) Regarding sections 2 and 3 on page 2 of the Office Action, the literally translated abstract has been editorially revised and rewritten to avoid means language in the abstract. Withdrawal of the objection to the abstract is respectfully requested.
- 3) Regarding section 4 on page 2 of the Office Action, the specification has been editorially revised to provide the required subheadings and to avoid the effects of an originally filed literal translation of the corresponding German text. The editorial revisions and corrections of the <sup>substitute</sup> specification are supported by the context and by the originally filed drawings and do not include any new matter.
- 4) Referring to the originally filed specification page 5, lines 22 to 33, this paragraph refers to a "quasi-stationary operating state". The meaning of this term has now been explained at the end of the same paragraph. Such explanation does not contain any new matter.
- 5) On pages 7, line 20 of the original specification "0.5th order" has been changed to --1.0st order-- because the 0.5th order

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cannot be both closest and second next to the measured phase.  
Thus, the whole paragraph supports this correction.

- 6) On page 14, line 20 of the original specification "independent from" has been corrected to --as a function of--. This correction is supported by the context.
- 7) The rejection of all previous claims 1, 2 and 24 to 44 under 35 USC §112(2) is respectfully traversed as not applicable to new claims 45 to 57. Claims 45 to 57 replace all previous claims 1 to 44. The new claims have been drafted in accordance with US practice. Means language has been avoided in the new method claims 45 to 52 and in the new apparatus claims 53 to 57. Claim 53 defines an apparatus for performing the method of independent claim 45. New method claims 45 to 52 are supported by original claims 1 to 13. New apparatus claims 53 to 57 are supported by original apparatus claims 14 to 23. The new claims 45 to 57 and the new abstract do not contain any new matter. Withdrawal of all rejections under 35 USC § 112(2) and withdrawal of all claim objections are respectfully requested.
- 8) The rejection of claims 1, 2 and 24 to 44 as being unpatentable under 35 USC § 103(a) in view of US Patent 6,021,758 (Carey et al.) taken in the light of US Patent 6,357,287 (Jin) and further in view of US Patent 5,479,818 (Walter et al.) is respectfully traversed for the following reasons. Taking these references in conjunction, the resulting combination neither teaches nor suggests the combination of features now set forth in new

independent claims 45 and 53 and in the respective dependent claims 46 to 52 and 54 to 57.

- 9) More specifically, new claims 45 and 53 define the steps and feature required for using the same sampled engine speed signals for performing several different engine controls. These several different engine controls which are based on the processing of the same sampled speed signals include:
- step (d) of claim 45: a cylinder classification,
- step (e) of claims 45: an identification of a cylinder that does not run evenly, an identification of a fuel adjustment direction (more or less fuel quantity), and determining a specific fuel quantity for the correction of the uneven running,
- step (f) of claim 45: generating a control signal and controlling the specific fuel quantity, to correct the uneven running,
- step (g) of claim 45: detecting a misfiring,
- steps (h to k) of claim 45: detecting an actual power output and correcting the actual power output if it deviates from a rated power output. The performance of all correcting steps based on the same speed measurements is the core of the present invention. Further details are defined in claim 45 set forth above. Apparatus claim 53 comprises the components required for performing the present method steps.
- 10) It is recognized in the Office Action (page 5, sec. 11 lines 7, 8) that the primary reference US Patent 6,021,758 (Carey et al.) does not disclose a frequency analysis device and also does not disclose the application of a Hartley-Transformation. Carey et

al. determine a cylinder imbalance of the engine from a phase analysis. Please see in this connection col. 1, lines 61 and 62 as well as column 2 lines 7 and 8. The steps performed by the teaching of Carey et al. are based on using the fluctuations in the engine speed to detect an unbalanced engine, col. 1, line 42 to line 45. The result of Carey's steps following a Fourier transformation is used to correct the imbalance by applying so called "trims" to the fueling commands for each individual cylinder (col. 1 lines 43 to 45). Carey et al. do not perform the several different corrections and information acquisition such as determining whether any cylinder misfired and if so which cylinder of the engine has misfired.

- 11) US Patent 6,357,287 (Jin) also performs a frequency analysis by using a discreet Fourier transformation to discover a misfire or combustion failure of the engine in general without identifying an individual cylinder that has misfired or in which the combustion has failed. Please see col. 2 lines 4 to 19 of the Jin disclosure. Jin teaches in a further step to transform the base function resulting from the discrete Fourier transformation, into a trigonometric function and to further transform that trigonometric function into a Walsh Function (col. 2 lines 13 to 15). A misfiring or combustion failure of the engine is recognized when the amplitude of a frequency component becomes larger than a reference value (see col. 4 lines 15 to 17). Jin et al. do not teach anything beyond their misfire detection of the engine as such. Jin et al. do not teach any identification of an individual cylinder has misfired because the combustion has

failed. Jin et al. do not make any suggestion regarding any quiet run closed loop control nor any cylinder classification nor any power output control in response to a misfiring. Thus combining Carey et al. with Jin or vice versa does not provide any motivation nor suggestion toward the present combination of steps and components as set forth in the above new claims 45 to 57.

- [12) US Patent 5,479,818 (Walter et al.) has been cited as disclosing the application of a fast Hartley-Transformation to a signal that represents pressure variations that indicate so-called fouling in an axial compressor. These pressure responsive signals are transformed by means of a Hartley-Transformation for the purpose of monitoring fouling in the axial compressor or at least one stage in such an axial compressor. The teaching according to Walter et al. does not suggest the identification of combustion failures of uneven running cylinders, of fuel quantities (more or less fuel) for correcting individual, identified cylinders of an internal combustion engine. The invention accomplishes all of these advantages from the same sampled signals. Moreover, Walter et al. solved their problem in the time frequency domain not in an angular frequency domain. Further, for the purpose of Walter et al. namely detecting fouling in an axial compressor the evaluation of amplitude information is sufficient. Therefore, combining Walter et al. with Carey et al. and Jin does not result in a combination as claimed above, much less is there any suggestion that the Hartley-Transformation could be used for the present purposes. Hence, there is no suggestion in Walter et al.

to replace the use of a fast Fourier transformation either in Carey and/or in Jin by a Hartley-Transformation. A Hartley-Transformation of compressor pressure signals does not suggest using the Hartley-Transformation for the processing of engine speed signals.

- 13) Even if the Hartley-Transformation is employed in the context for example, of Jin (US Patent 6,357,287), no detection of individual cylinders that have an uneven running or a combustion failure would result because neither Jin nor Walter et al. teach classifying or identifying individual cylinders that operate below an acceptable standard.
- 14) Summarizing, the frequency and phase analysis according to the invention provides amplitude information and phase information of different frequency orders. The exceeding of a reference amplitude value signifies an uneven running and/or a combustion failure and according to the invention the cylinder or cylinders having an uneven running or a combustion failure are identified. Further, any cylinder with an uneven running since it is individually identified can be individually corrected by increasing or decreasing the injected fuel for that individual cylinder or cylinders. Further, the invention corrects a power or torque output that is below a rated output. Combining the three references does not result in a suggestion for achieving all the controls from the same speed measurements.

- 15) Favorable reconsideration and allowance of the application, including all present claims 45 to 57, are respectfully requested.

Respectfully submitted,  
Reinhold HAGEL et al.  
Applicant

WGF:he/4815  
Enclosures:  
Transmittal Cover Sheet  
Term Extension Request  
Form PTO-2038  
Drawing Transmittal w.  
1 Replacement Sheet  
Substitute Specification  
(Marked-Up Version)  
Substitute Specification  
(Clean Version)  
postcard

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SUBSTITUTE SPECIFICATION AND ABSTRACT (Marked-Up Version)

Description

Title of the Invention

Control of the operating mode of an internal combustion engine

Field of the Invention

The invention relates to a closed loop control method for controlling the operating mode of an internal combustion engine as well as to a device for controlling the operating mode of an ~~IC-engine~~ internal combustion engine of a motor vehicle ~~by means of said~~ in accordance with the present method.

Background Information

In particular, the invention relates to a method for detecting and controlling in a closed loop the uneven running of an IC engine. A control device embodying a method of this type, which typically exists with modern vehicles, is e.g. also known as Engine Smoothness Control (ESC). Many cases of engine smoothness control systems of this type are known, so that the design and functionality of the different, known engine smoothness control systems is not explained in detail hereinafter.

Based on the unavoidable existence of process tolerances of the injection system as well as by the occurring ageing effects different fuel quantities are proportioned to the cylinders. Even minor differences of the fuel quantities supplied to the cylinders result in torque variations, what may be the cause of unwanted vibrations for examples of mirrors, steering wheels and the like. Such vibrations have a particular unwanted influence in case of the IC engine of the motor vehicle, as here the engines are often rocked, which must be taken into consideration when dimensioning the engine construction, as this may possibly have a negative impact on the life time of the engine. Moreover, ~~by the said dispersion of~~ the above mentioned differences in the injected fuel quantity have an unfavorable ~~impact~~ influence on the noise, the life time and on the emissions of the IC engine ~~is exerted. engine.~~ It is understandably essential to avoid these unwanted ~~impacts.~~ influences.

The ~~[[said]]~~ above mentioned torque variations are reflected for instance in the instantaneous crankshaft speed and in the instantaneous crankshaft acceleration, ~~resp. They~~ which can be measured and analyzed in the engine control device.

#### Summary of the Invention

Starting from here it is the object of the present invention to avoid or at least diminish to the greatest possible extend the torque changes or variations at a uniform crankshaft speed.

This object ~~is attained~~ has been achieved in accordance with the invention by ~~a method with the features of claims 1, a control device with the features of claim 19 and an IC engine with the features of claim 23.~~ controlling, in closed loop fashion, the operation of an internal combustion engine including engine cylinders by performing the following steps:

- a) sampling an engine speed signal,
- b) applying a Hartley-transformation to said engine speed signal for transforming said engine speed signal into an angular frequency range,
- c) analyzing said angular frequency range for producing individual angular frequency orders representing phase information and amplitude information,
- d) performing a cylinder classification based on said phase information and said amplitude information by first comparing said phase information with a given reference phase value and by second comparing said amplitude information with a given first amplitude threshold value, said first comparing and said second comparing yielding individual cylinder informations for each cylinder of said engine cylinders,
- e) processing said individual cylinder informations for identifying, based on said first phase comparing, any cylinder which is causing an uneven running of said internal combustion engine for further identifying, also based on said first phase comparing, a fuel adjustment direction for each individual cylinder

including said cylinder causing said uneven running,  
and for determining, based on said second amplitude  
comparing, an injection fuel quantity required for  
correcting said uneven running of said internal  
combustion engine,

- f) generating in response to said processing a closed  
loop control signal and applying said closed loop  
control signal to an engine controller for correcting  
said uneven running of said internal combustion  
engine,
- g) detecting a misfiring of any one of said engine  
cylinders by further comparing said amplitude  
information with a respective second given amplitude  
threshold value to provide information for concluding  
whether said uneven running is caused by said  
misfiring when said amplitude information exceeds said  
respective second given amplitude threshold value,
- h) detecting an actual power output of said internal  
combustion engine,
- i) comparing said actual power output with a rated power  
output of said internal combustion engine to provide  
a reduced power output information,
- j) modifying said closed loop control signal in response  
to said reduced power output information, and
- k) applying said modified closed loop control signal to  
said engine controller for controlling a fuel  
injection to all said engine cylinders for correcting

said actual power output with reference to said rated power output.

~~Accordingly, it is provided:~~

~~A control method for controlling the operating mode of an IC engine, in which a control device comprises a device for sampling signals, a downstream arranged device for frequency analysis and a downstream arranged device for cylinder classification, in which at first a speed signal is detected and subsequently the speed signal is transformed into an angle frequency range, the transformation being effected by means of a Hartley transformation (patent claims 1).~~

According to the invention there is further provided an apparatus for performing the present method. Such apparatus comprises the following components: a speed signal sampling sensor for generating an engine speed signal, a frequency analyzer having an input for receiving said engine speed signal for performing a Hartley-transformation on said engine speed signal thereby converting said engine speed signal into an angular frequency range, said frequency analyzer producing from said angular frequency range individual angular frequency orders, a cylinder classifier having an input connected to an output of said frequency analyzer, and a controller having an input connected to an output of said cylinder classifier for receiving an input signal from said cylinder classifier for generating a closed loop control signal, said controller having an output connected to

said internal combustion engine for said closed loop control, wherein said signal sampler sensor, said frequency analyzer and said cylinder classifier are adapted for detecting a misfiring cylinder of said internal combustion engine, and wherein said signal sampler sensor, said frequency analyzer, said cylinder classifier and said controller are further adapted for generating closed loop control signals for said internal combustion engine for tracking any one of an engine torque and an engine power output.

~~A device for controlling the operating mode of an IC engine of a motor vehicle with a device for sampling signals, with a device for frequency analysis being arranged downstream to the device for sampling signals and with a device for cylinder classification being arranged downstream to the device for frequency analysis (patent claim 14).~~

~~An IC engine in a~~ A motor vehicle with an IC engine having at least one cylinder and with at least one engine control, at least one engine control comprising a device for controlling the operating mode of an IC engine of a motor vehicle (patent claim 23). equipped or controlled according to the invention is part of the invention.

The method according to the invention is able to detect the uneven running starting from a detected speed signal and to diminish it by an adequate adjusting adjustment of the injected fuel quantities. This adjustment is effected in accordance with

the invention by a closed loop control system, which recognizes which cylinder(s) is/are to be adjusted. Advantageously, the control system provides also an information, which discloses apart from the qualitative information also a quantitative information on the extent of the adjustment, i.e. which cylinder is to be adjusted to what extent.

For this purpose the speed signal is transformed into an ~~[[angle-]]~~ angular-frequency-range thereby obtaining spectral components or individual frequencies of this angular frequency range. ~~[[The]]~~ These spectral portions obtained in this way components or individual frequencies are also called orders. Advantageously, the transformation is effected with the aid of the Hartley-transformation. ~~[[As]]~~ Since the adjustment of single cylinders, in particular, has an impact on the ~~low-frequent~~ low-frequency spectral portions orders, primarily these ~~low-frequent~~ low-frequency spectral portions orders diminish the uneven running. ~~To adjust~~ For adjusting the uneven running to zero, a solution ~~may be to~~ is seen in correcting primarily ~~correct~~ these ~~low-frequent~~ low-frequency spectral portions to zero. For this purpose a controller is ~~assigned to~~ provided for the IC engine, which drastically reduces the disturbing spectral portions in the entire operating range and thus clearly improves the vibration behavior of the entire drive ~~[[chain-]]~~ train.

The invention further relates to a method for detecting misfires of an IC engine. ~~A device of this type is usually known~~ engine referred to as Misfire Detection.

The invention further relates to a method for detecting and controlling the released mean torque and the mean power, resp., of an IC engine.

~~Advantages and further embodiments of the invention idea will become apparent from the further subclaims taken in conjunction with the drawing and the description.~~

#### Brief Description of the Drawings

*This should not be made*

~~Fig. 1~~ shows a block diagram of a control device according to the invention for an IC engine, on the basis of which the method according to the invention is shown; and

Fig. 2 shows a detailed block diagram, which ~~demonstrates~~ illustrates in more detail the block of the cylinder classification.

#### Detailed Description of Preferred Example Embodiments and of the Best Mode of the Invention

Like reference numerals refer to like elements or elements with identical functions throughout all views, unless otherwise mentioned. In this context the term "control" refers to a closed loop control.



~~Figs. 1 shows the block diagram of a control device according to the invention for an IC engine, with the aid of which the method according to the invention is described.~~

In Fig. 1 a self-igniting IC engine in a vehicle is shown under reference numeral 1 and the control device according to the invention for controlling the cylinder adjustment of the IC engine is shown under reference numeral 2.

The control device 2 comprises a device for sampling signals 3, which detects a rotation of the crankshaft and which generates a signal derived from it. This typically digital signal is supplied to a downstream arranged device 4, which starting from the signal supplied by the device for sampling signals 3 averages an arithmetic mean value. Subsequently, this information is delivered to a device for frequency analysis 5, which performs a spectral analysis. This spectral analysis is then further processed in a correction device 6, which corrects the frequency portions. With the data or information obtained in this way a cylinder classification is performed in a device 7 which is described in detail hereinafter. At the output of the device 7 a classification signal can be tapped, which can be supplied to a downstream controller 8. The controller 8 generates from it a control signal, which can be injected into the IC engine so that the cylinders can be adapted optimally to the given conditions in accordance with the requirements.

Though in Fig. 1 devices 4, 6 have been shown, it must be pointed out that one could do also without one or both of these ~~elements~~ devices, without considerably affecting the ~~functionality~~ function of the control method and device according to the invention.

Further, the present invention is not ~~[[be]]~~ restricted to self-igniting IC engines, but can ~~principally~~ also advantageously be used , in principle, with any ~~however embodied~~ IC engines ~~[[!-]]~~ however embodied.

Fig. 2 shows a detailed block diagram for illustrating the device 7 for cylinder classification. The device 7 contains in a first segment a means for reference phase generation 71, to which means for reference phase calibration 72 and reference phase selection 73 are downstream arranged. In a second segment a device 74 is provided, for which e.g. assessment criteria are determined or calculated, which are accessible later on. Based hereupon the main causers and/or the secondary causers of a disturbance or a deviation are determined. In addition or as an alternative, a possible adjustment for correcting the disturbance and deviation, resp., can be derived already at this moment. In the downstream unit 76 the qualitative and, if necessary, also the quantitative degrees of adjustment can be determined.

The ~~functionality~~ function of the present invention ~~[[is]]~~ will now be described in detail with ~~the aid of~~ reference to Figs. 1 and 2 as follows:

The method according to the invention is primarily based on the analysis of the engine speed. For this e.g. a transmitter wheel with preferably equidistant angle markings is arranged at the crankshaft. The time periods between the individual markings of the rotating transmitter wheel are detected by a sensor, for instance an inductive or an optical sensor. Subsequently, the signal detected in this way is converted into revolution speeds in a program-controlled unit, for instance a microcontroller, microprocessor or the like. This program-controlled unit can be a component of the control device 2 according to the invention or can also be contained in the engine control. Conversely, also the control device 2 according to the invention can be a component of the engine control.

Thus ~~[[in]]~~ equidistant angle distances sampling values of the crankshaft speed are available. The number of the angle markings is to be chosen to be high enough that the sampling theorem can be complied with.

In case of a quasi-stationary operating state the arithmetic mean value is averaged starting from at least two successive crankshaft speed segments ~~[[of the]]~~ having a length of 720° of ~~the crankshaft~~. The crankshaft speed segments of the length 720° ~~of the crankshaft~~ are also called working ~~cycle~~. cycles. Averaging the arithmetic mean value serves to eliminate cyclical variations which result from an uneven combustion. In addition or as an alternative, the arithmetic averaging could also be performed ~~[[also]]~~ in the angle-frequency range. For ~~this said~~

this purpose the above mentioned Hartley frequency transformation must be applied to each individual analyzable working cycle. In a further embodiment one could do ~~[[also]]~~ without the device 4 for arithmetic averaging, although the invention with a device for arithmetic averaging ~~[[shows]]~~ functions better functionality. The device 4 for arithmetic averaging could also be arranged at another place in the control device 2. A "quasi-stationary operating state" as mentioned above, means in this context that engine operating parameters at the beginning and at the end of an engine speed signal sampling cycle differ only insignificantly from each other.

In the ensuing method step the averaged speed signal (cycle duration 720° of the crankshaft) is subject to a spectral analysis. For the transformation a Discrete Hartley-Transformation (DHT) is performed in accordance with the invention. The said DHT-Transformation, which stems from image processing, unlike the Fourier Transformation which is usually used and widely spread in digital signal processing and telecommunications offers the particular advantage that it can be calculated by exclusively real operations. Here, the speed signal is separated into individual angle-frequencies, also called orders, which serve for assessing the uneven running. Here, the vibrations show a frequency, which is smaller than double the engine speed. As the adjustment of individual cylinders mainly affects the amplitudes of the low-frequent vibrations, in case of a 4-cylinder engine the amplitudes of the 0.5th and of the first order represent the actual values for

uneven running. Said orders, hereinafter referred to as relevant orders, can be affected by the injection and designate vibrations with the frequency of half and simple engine speed, respectively. These are clearly diminished by means of the method according to the invention. In this connection the value zero represents the nominal value for the amplitude of the 0.5th and of the first order. Complex numerical values can be derived from the spectral transformation applied to the speed signal, which values can be converted for the respective orders into quantity (or amplitude) and phase.

~~At this place is~~ Here it must be noted that in case of a 6-cylinder engine in addition the 1.5th order, in case of an 8-cylinder engine in addition the 1.5th and the second order would have to be taken into account.

~~[[As]]~~ Since the calculated complex numerical values ~~[[and]]~~ namely amplitude and amplitude values and phase values, resp., representing informations are generally tampered due to typically appearing parasitic effects (transmitter wheel or sensor errors, moments of inertia, etc.), these are eliminated with the aid of an advantageously ~~provided~~, provided so-called towed correction. For this ~~[[in the]]~~ purpose a stationary towed operation, ~~i.e.~~ in the is performed. A towed operation is an operating state without fuel injection, injection. In such a towed operation measurements are ~~performed~~ made for instance of the instantaneous crankshaft speed. The subsequent application of the Hartley-Transformation delivers speed-dependent correction values for the

vibrations of the 0.5th and of the ~~[[first]]~~ 1.0st order. These correction values are stored in the control device.

One can do also without this device 6 for correcting the frequency ~~portion~~ orders, although the control device 2 according to the invention ~~would show functions~~ better ~~functionality~~ with this device 6. Moreover, this correction device 6 could perform ~~also another~~ a correction other than the towed correction.

The ~~adjusted~~ cylinders to be adjusted are detected with the aid of speed and load dependent reference phases, which are stored in the control device 8 for the relevant orders. Subsequent to the determination of the reference phases, which may be ~~effected~~ at the dynamometer obtained from an engine testing stand or in the driving mode, ~~these are equally subject~~ the reference phases are also subjected to a towed correction. In addition a calibration factor can be derived from the combination of the relevant orders of the reference phases ~~a calibration factor can be derived~~.

The corrected engine orders represent the basis for the next method step. If the amplitudes of the vibrations of the 0.5th and of first order exceed a given threshold value and if a quasi-stationary operating state is on hand, the control is activated.

Reference phases are assigned to the measured phases of the 0.5th and of the first order (1.0st order). The reference phase of the

0.5th order, which is ~~adjacent~~ closest to the measured phase, is referred to as the primary phase, the related cylinder as the primary or first cylinder. The reference phase of the ~~[[0.5th]]~~ 1.0st order, which is the second ~~[[next]]~~ closest to the measured phase is referred to as the secondary phase and the related cylinder as the secondary or second cylinder.

By means of the reference phases assigned to the measured phases and the measured amplitudes and phases assessment criteria are established while taking into account the respective load and speed situation, with the aid of which criteria the cylinders to be adjusted and their necessary direction of adjustment are determined. In the present case four assessment criteria are determined, which are referred to hereinafter as PK1-value, PK2-value, PK3-value, AK-value.

By means of the primary phase, the reference phase of the first order and a calibration factor a so-called PK1-value is calculated, which is compared with a given threshold. Equally, a so-called PK2-value is calculated from the primary phase, the secondary phase, the measured amplitude and the measured phase of the 0.5th order, which value is compared with a further given threshold.

Dependent from an exceeding of said thresholds the logic values "HIGH" and "LOW" are associated to the PK1- and PK2-values. Optionally, PK2 can also be determined from the measured phase and the primary phase, i.e from the distance of both phases.

As a further criterion the so-called AK-value is required. For determining the AK-value the load and speed dependent ratio of the measured amplitudes of the 0.5th and of the first order are compared with a further amplitude threshold value. The comparison with ~~[[\*]]~~ the further amplitude threshold value delivers the logic value "HIGH" and "LOW", resp., for the AK-value. In addition or as an alternative, also a so-called PK3-value, which is determined by means of the primary phase, a complementary primary phase (=phase of the cylinder not ~~adjacent~~ closest to the primary cylinder), the measured amplitude and the measured phase, can be compared with a still further threshold, thus ~~resulting~~ obtaining the logic value "HIGH" or "LOW" for the PK3-value ~~the logic value "HIGH" or "LOW"~~.

In a further method step, the respective cylinder to be adjusted and if necessary also the respective necessary adjustment ~~device~~ direction are ~~determined.~~ determined, said direction indicating whether acceleration or deceleration of the engine is required.

The PK1-value is used for determining the relevant adjusted cylinder, for instance the main causer of the adjustment, and its direction of adjustment. If for instance PK1="HIGH", the main causer of the adjustment is the cylinder related to the primary phase. Moreover, the identified cylinder is too greasy, i.e. a too large fuel quantity is supplied to the cylinder. In this case the injected fuel quantity of this cylinder should be reduced.



The values PK1 and PK2 combined with the AK-value - optionally also with the PK3-value - reveal the cylinder with the second highest portion of the adjustment (=secondary causer) as well as its direction of adjustment.

The contribution of adjustment of the secondary causer is typically determined relatively to the main causer. The relative contribution of the secondary causer can be determined in analytic manner. As an alternative, the secondary causer can be suppressed. In this case typically merely a single cylinder, namely the main causer, is adjusted.

The measured relevant orders are advantageously compensated or at least diminished to the greatest possible extent by generating ~~the adequate~~ corresponding counter vibrations. For this purpose the determined qualitative adjustments of the main causer and/or the secondary causer or causers are distributed to all cylinders such that the sum of the adjustments over all ~~[[4]]~~ four cylinders equals or nearly equals zero. ~~By means of this~~ This compensation does not change the original engine torque and the original engine power, ~~resp. are not changed~~ respectively.

The amplitudes of the relevant orders represent ~~the offset~~ a control deviation and are ~~subject~~ subjected to a speed and load dependent weighting. Finally, with the aid of the determined qualitative adjustments and the actual amplitudes of the relevant orders, individual, quantitative correction factors are determined. These correction factors are supplied to a closed

loop controller 8, which in the case that there is no controller ~~restriction~~ limitation, ~~affects~~ influences the individual injected fuel quantities necessary for the respective cylinders. In the present example ~~[[of]]~~ embodiment the controller 8 is a simple I-controller. However, ~~it goes without saying that also~~ any control device could be used here, which ~~dependent from~~ depends on the determined correction values, and which provides a control signal at ~~the side of the~~ its output.

Apart from the now described functionality the control device according to the invention comprises advantageously also additional functionalities. The functionalities of the controlling device according to the invention described hereinafter can be implemented additionally or as an alternative to the above described control of the uneven running of an IC engine (ESC-control).

#### Misfire Detection

Due to the unwanted occurrence of misfires that are unavoidable ~~[[with]]~~ in an IC engine ~~unwanted~~, non-burned fuel can be released into the environment. Moreover, this may result in a permanent damage of exhaust gas treatment systems existing in modern vehicles, for example of the catalytic converter. Both implicate that the vehicle exhaust pollution of the environment is increased. To avoid this to the greatest possible extent there are national and international regulations and laws (e.g.

OBD II, E--OBD), which prescribe inter alia a device for recognizing misfires in motor vehicles.

The occurrence of misfires leads to torque variations, which reflect for example in the instantaneous crankshaft speed and in the instantaneous crankshaft acceleration, resp. By means of the method according to the invention described hereinafter it is possible to detect misfires starting from a speed signal. Further it is possible to recognize which cylinder has misfires. For this the speed signal is transformed into the angle-frequency range in an appropriate manner as in the engine smoothness control. As the adjustment of individual cylinders mainly impacts the low-frequent spectral portions, these are primarily used for detecting misfires.

The method according to the invention in turn is based on the analysis of the engine speed. For this purpose e.g. a transmitter wheel with preferably equidistant angle markings is arranged at the crankshaft. The periods between the individual markings of the rotating transmitter wheel are detected by a sensor and are subsequently converted in the microcontroller into speeds.

~~By means of this the sampling~~ When sampling engine speed signals  
the sampled values of the crankshaft speed are determined in equidistant angle distances. Here it must be ensured that the number of angle markings on the speed sensor is high enough so

that compliance with the sampling theorem ~~can be complied with~~  
~~in any case.~~ is assured.

In case of a quasi-stationary operating state a 720° long section of the speed signal, which may also be referred to as working cycle, is ~~subject~~ subjected to a spectral analysis by means of a Discrete Hartley-Transformation (DHT). ~~[[The]]~~ In the analysis ~~the~~ speed signal is separated into individual angle-frequencies, which serve for detecting misfires. ~~[[As the]]~~ The adjustment of individual cylinders mainly affects the amplitudes of the vibrations, which have a frequency smaller than double the engine ~~speed with a~~ speed. Therefore, in a 4-cylinder engine the amplitudes of the 0.5th and of ~~[[first]]~~ 1.0st order represent sizes from which conclusions can be drawn to the existence of misfires. The said orders, hereinafter referred to as relevant orders, designate vibrations with the frequency of half ~~and~~ simple the engine speed, or the actual engine speed. ~~respectively. At this place is must be~~ It is noted that in case of a 6-cylinder engine in addition the 1.5th order, in case of an 8-cylinder engine in addition the 1.5th and the second order would have to be taken into account. In general, the spectral transformation applied to the speed signal delivers complex numerical values, which ~~[[can be]]~~ are converted for the respective orders into ~~quantity and~~ amplitude and phase values, ~~[[resp.]]~~ respectively.

As the calculated complex numerical values ~~[[and]]~~ or rather the amplitude- and phase values, ~~[[resp.]]~~, are generally ~~tampered~~

falsified due to always appearing parasitic effects - for instance a transmitter wheel or sensor error, an error of the moment of inertia, etc. - these are eliminated with the aid of a so-called towed correction. For this purpose ~~[[in the]]~~ measurements are made in a stationary towed operation (=operating state without fuel injection), ~~measurements are performed~~ for instance of the instantaneous crankshaft speed. The subsequent application of the Hartley-Transformation delivers advantageously speed-dependent correction values for the vibrations of the 0.5th and of the ~~[[first]]~~ 1.0st order. These correction values are stored in the control device 8.

The occurrence of one or more simultaneously appearing misfires ~~[[leads]]~~ causes the amplitudes of the relevant orders to increase strongly. By analyzing ~~[[the]]~~ these increased amplitudes the occurrence of a misfire can be displayed. The comparison of the amplitudes with a respective given threshold is performed in a so-called amplitude discriminator. ~~It states~~ which indicates the existence of misfires for each working cycle.

If for example the amplitudes of the 0.5th and of the first orders lie below the said threshold, there is no misfire. If both exceed them, it is recognized that either one cylinder or three cylinders have a misfire. Two misfires of adjacent cylinders are recognized if only the amplitude of the 0.5th order exceeds the threshold. Two misfires of complementary, i.e. cylinders that are not adjacent in the firing order, are on hand

if only the amplitude of the first order exceeds the threshold.

The determination or detection of the ~~cylinders~~, cylinders which ~~have misfires~~ misfired, is effected in the block 7 (cylinder detection classification) with the aid of speed and load dependent reference phases, which are stored for the relevant orders in the control device. Subsequent to the determination of the reference phases, which may be effected at the dynamometer or in the driving mode, these are equally subject to a towed correction. In addition, from the combination of the relevant orders of the reference phases a calibration factor can be derived. Reference phases are assigned or correlated to the measured phases of the 0.5th and of the ~~[[first]]~~ 1.0st order. The reference phase of the 0.5th order and the related cylinder, ~~resp.~~, which is closest to the measured phase of the 0.5th order, ~~delivers~~ designates the so-called primary or first cylinder.

By means of the reference phases and the calibration factor a reference phase ~~criteria~~ criterion is determined. By taking into account the respective threshold exceedings in the amplitude discriminator and the knowledge of the primary cylinder the misfiring cylinders are identified.

Torque ~~tracing~~ tracking - Performance ~~tracing~~ tracking

Due to the unavoidable occurrence of ageing effects of the engine and above all of its injection system the engine torque released by the IC engine and the released engine power, ~~[[resp.]]~~

respectively, diminish over the years. This effect is considered as a deficiency in particular with commercial vehicles, as they demand much higher engine running times as required ~~[[with]]~~ for passenger cars. Exchanging the engine is too expensive on the one hand and on the other hand ~~[[the]]~~ a commercial vehicle also will ~~[[fail]]~~ not be usable for a longer period of time. In particular, the occurrence of manufacturing tolerances causes a more or less strong variation in the engine torque and as a consequence thereof a dropping of the engine power, which can often only be compensated by time-consuming ~~strip-end compensation.~~ compensation at the end of an assembly line when an engine is manufactured.

By arranging torque sensors or cylinder pressure sensors in the cylinders the engine torque and the engine power, resp., can in fact be determined, however, this requires additional structural expenditure. Variations in the released engine torque and in the released engine power, resp., reflect for instance in the instantaneous crankshaft speed and instantaneous crankshaft acceleration, resp. These can be analyzed in the engine control device while using an already existing sensor.

By means of the method according to the invention hereinafter described, it is possible to detect the released engine torque and the released engine power, resp., starting from the speed signal as well as to affect or correct this by an appropriate adjustment of the injected fuel quantities.

As the combustion energy is substantially contained in marked frequency portions of the speed signal, it is transformed into the angle-frequency range. The resulting spectral portions are also referred to as orders. By analyzing the amplitude of the vibration of the second order in case of a 4-cylinder engine conclusions can be drawn to the released engine torque and the released engine power, resp. As an alternative, also the 4<sup>th</sup>, 6<sup>th</sup>, 8<sup>th</sup>, etc. orders can be used for this. Accordingly, for instance with a 6-cylinder engine the amplitude of the vibration of the 3<sup>rd</sup> order and with an 8-cylinder engine the amplitude of the vibration of the 4<sup>th</sup> order and the even-numbered multiples of the said orders, resp., are analyzed.

After ~~an adequate~~ a suitable calibration the ~~[[said]]~~ mentioned spectral portions represent actual ~~quantities for values of the~~ released generated engine torque and the ~~released generated~~ engine power, ~~[[resp.]]~~ respectively, and can be compared with the engine torque and the respective engine power, ~~[[resp.]]~~ respectively, demanded by the closed loop engine control device. ~~A controller is assigned to the IC provided for the engine, which~~ minimized the difference between an actual engine torque and a nominal engine torque by varying the injected fuel quantity.

~~[[The]]~~ This embodiment of the method according to the invention is based on the analysis of the engine speed just as in the above described embodiments of the present methods. Here, ~~in turn~~ again a transmitter wheel arranged at the crankshaft is provided with preferably equidistant angle-markings. The periods of time,



which occur ~~with a rotating~~ when the transmitter wheel rotates, between the individual markings of the rotating transmitter wheel are detected by a sensor and converted by a microcontroller into speeds assigned to these periods. Thus, in equidistant angle distances sampling values of the crankshaft speed are available. Also in this case it ~~[[is to]]~~ must be ensured that the number of samples taken is high enough to satisfy the sampling theorem ~~is always complied with.~~

In case of a quasi-stationary operating state the arithmetic mean value is averaged starting from at least two successive crankshaft speed segments ~~[[of]]~~ having the length of 720°. ~~720° of the crankshaft.~~ ~~This serves to eliminate~~ Such averaging eliminates cyclical variations which result from an uneven combustion.

In the ~~ensuing~~ following method step the averaged speed signal (cycle duration 720° of the crankshaft) is ~~subject~~ subjected to a spectral analysis by means of a Discrete Hartley-Transformation (DHT). ~~Here (DHT), whereby~~ the speed signal is separated into individual angle-frequencies, wherein in the method according to the invention the torque information is generated from the amplitude of the vibration of the second order (=vibrations with the frequency of the engine speed). Complex numerical values are generally provided by the spectral transformation applied to the speed signal, which values can be converted ~~into quantity and quantitatively into~~ amplitude, resp., and phase. phase values representing respective informations.

As the calculated complex numerical values ~~[[and]]~~ or rather amplitude- and phase values, ~~[[resp.]]~~, are generally tampered due to typically appearing parasitic effects (e.g. transmitter wheel errors, moments of inertia, etc.), these are eliminated with the aid of a correction device (i.e. towed correction). For this ~~[[in the]]~~ purpose measurements for instance of the instantaneous crankshaft speed, are made in a stationary towed operation (=operating state without fuel injection). ~~measurements are performed for instance of the instantaneous crankshaft speed.~~ The subsequent application of the Hartley-Transformation ~~delivers~~ to these measurements provides speed-dependent correction values for the vibration of the second order. These correction values are stored in the control device.

As the amplitude of the second order, which is a measurement for the released engine torque and the released engine power, resp., increases with a fixed speed strictly monotonously with the load, it can be ~~detected in case of~~ ascertained in or from a reference engine and can be stored ~~independent from~~ as a function of the speed in a family of reference characteristics. This family of characteristics then serves as a reference for detecting the actual engine torque and the actual engine power, resp.

In addition or as an alternative, the calculation of the actual engine torque and of the actual engine power, resp. can be performed in an analytic manner.

The difference between the nominal engine torque requested by the engine control device and the ~~de-facto~~ actual engine torque is detected by ~~an ensuing~~ a closed loop control system and is minimized by varying the injected fuel quantity. Before processing the introduced method the speed strokes can also be equated by means of a so-called engine smoothness control (ESC).

The above examples of embodiment have been depicted by way of an IC engine with four cylinders. However, the invention is not to be restricted to exclusively IC engines of this type, but can, of course, also be extended to IC engines with more or less than four cylinders in case of adequate adaptations that are obvious to the expert.

~~The above examples of embodiment describe the invention by way of a Hartley Transformation. However, in case of an adequate modification the invention can also very advantageously been used with the aid of another transformation, e.g. a Fast Fourier Transformation (FFT), a Discrete Fourier Transformation (DFT) or the like, although the invention is most advantageous and thus most suitable in the case of a Hartley Transformation.~~

In the above ~~examples of embodiment~~ example embodiments the arithmetic mean value was averaged respectively. However, the invention is not to be restricted exclusively on this, but can also very advantageously be used in case of a geometrical averaging of the mean value or the like.

~~Recapitulating, it can be ascertained that by the above described control system with the aid of the Hartley Transformation a control of the operating mode of the IC engine is realizable in a very elegant and nevertheless very simple manner while completely renouncing of solutions known so far.~~

~~The present invention has been demonstrated with the aid of the above description to best possible explain the principle of the invention and its practical application, however, the invention can, of course, be realized with an adequate modification in diverse other forms of embodiment.~~

Although the invention has been described with reference to specific example embodiments, it will be appreciated that it is intended to cover all modifications and equivalents within the scope of the appended claims. It should also be understood that the present disclosure includes all possible combinations of any individual features recited in any of the appended claims.

~~List of reference numerals~~

- ~~1 IC engine in a motor vehicle~~
- ~~2 Control system~~
- ~~3 Device for sampling signals~~
- ~~4 Device for averaging the arithmetic mean value~~
- ~~5 Device for frequency analysis~~
- ~~6 Correction device for correcting the frequency portions~~
- ~~7 Device for cylinder classification~~
- ~~71 Means for reference phase generation~~
- ~~72 Means for reference phase calibration~~
- ~~73 Means for reference phase selection~~
- ~~74 Device with given assessment criteria~~
- ~~75 Unit for determining main causers and/or secondary causers  
of a disturbance or a deviation~~
- ~~76 Unit for determining the qualitative and/or quantitative  
adjustment measures~~
- ~~8 (I) Controller~~

In the Abstract:

~~Control of the operating mode of an internal combustion engine~~

~~The invention relates to a control method for controlling the operating mode of an IC engine, in which a control device comprises a device for sampling signals, a downstream arranged device for frequency analysis as well as a downstream arranged device for cylinder classification, in which at first a speed signal is detected and subsequently the speed signal is transformed into an angle frequency range, wherein the transformation is effected by means of a Hartley transformation. The invention further relates to a device for controlling the operating mode of an IC engine of a motor vehicle by means of such method as well as an IC engine.~~

Combustion failures of an internal combustion engine are controlled in closed loop fashion by sampling an engine r.p.m. to obtain a speed signal. The speed signal is subjected to a Hartley-Transformation to obtain angular frequencies or engine orders which are further processed to identify the cylinder which had a combustion failure and thereby reduced an actual engine power output compared to a rated power output. A power output correcting signal is produced and supplied to the engine. The system for performing these steps includes at least a speed signal sampler, a frequency analyzer to perform the Hartley-Transformation, a cylinder identifier or classifier and

a controller which supplies the closed loop control signal to the engine.